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DEVELOPMENT OF CORRELATION BETWEEN DIFFERENT PROPERTIES OF PERVIOUS CONCRETE

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ABSTRACT

Pervious concrete is one of the effectual concrete pavement mixes to address a number of important environmental issues, such as recharging groundwater and reducing storm water runoff. Pervious concrete is produced by eliminating most or all of the fine aggregate in the mix, which allows unified void spaces to be formed in the hardened matrix. These interconnected void spaces allow the concrete to transmit water at relatively high rates. 10mm, 20mm, 40mm maximum size aggregates and 43 grade OPC was used for research work. Fifteen mixes were casted. Compressive strength, density, porosity and permeability of the fifteen mixes prepared with w/c ratio of 0.35 and cement to aggregate ratio as 1:8 were determined at curing age of 28 days. It is found that compressive strength, permeability, density & porosity depends upon the proportion of aggregates used, w/c ratio and the quantity of cement used. The present paper discusses an attempt made to correlate the compressive strength, density & permeability of pervious concrete with the proportion of different sizes of aggregate and w/c ratio.

KEYWORDS: Pervious Concrete, Compressive Strength, Density, Porosity & Permeability

Original Article

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INTRODUCTION

Due to fast urbanization, our cities are being covered with buildings and roads made of concrete more and more. This has a major blow on the ground water table because concrete is a material composed of aggregates and sand embedded in a hard matrix of material (cement) that fills the space among the particles and bound them together. Due to lack of water permeability and air permeability through the concrete pavement, the rainwater is not filtered underground. As a result, there is recurrent flooding on the roads and other areas in the cities even during small rainfall. In addition, it is tricky for soil to exchange heat and moisture with air, which make difficulty for plants to grow normally. Safety of traffic of vehicle and foot passenger also reduces during rainy day. The frequent flooding results in high maintenance cost of transport system and drainage system also.

This crisis can be tackled by the use of Pervious concrete which is completely different from conventional concrete and have great differ in physical characteristics from those of normal concrete. Pervious concrete also known as permeable concrete, porous concrete, gap grade concrete and no fines concrete is one of the possible material for decreasing the runoff coefficient [13,16]. It can be used for lower traffic roads, shoulders, sidewalks and parking lots because pervious concrete is the material which has high pores (15-25%) and has higher value of coefficient of permeability (120-130 l/m^2/min) with low compressive strength (3.5 – 28 MPa)

[13,16]. The identical coarse aggregate in combination with low water cement ratio (0.25 to 0.35) makes concrete with void contents ranging from 11% to 35% [14].

The high permeability of pervious concrete is highly important in reducing storm water runoff. Footpath or walkways in some of the Indian metropolis and other big cities are usually paved with interlocking tiles/blocks. Such pavements can not only help in replenishing the ground water table locally but would also transfer both water and air to root systems allowing trees to flourish. A saving of 20% in cement and 30% in aggregates had been reported using pervious concrete [1].

Keeping above in view, it is clear that pervious concrete is a simple technology and needs a serious consideration from the engineers and architects for a variety of application like parking areas and pedestrian walkways and platforms etc in India. The present study was planned with the objectives to drive the relationship between compressive strength, density, porosity, permeability of pervious concrete and to drive prediction equation.

MATERIALS

2.1 Cement: Ordinary Portland cement of 43 grade was used. It was tested as per Indian Standard Specifications, IS: 8112-1989. Physical properties of cement were determined and shown in Table 1

Table 1: Properties of OPC 43 Grade Cement

Sr. No.	Characteristics	Value Obtained Experimentally	Values Specified by IS- 8112:1989
1.	Specific Gravity	3.17	-
2.	Standard consistency (%)	31	-
3.	Initial Setting time	167 minutes	30 minutes (minimum)
4.	Final Setting time	290 minutes	600 minutes (maximum)
5.	Fineness (%)	2.0	
6.	Compressive Strength 3 days 7 days 28 days	 24.62 MPa 33.07 MPa 45.76 MPa	 23 MPa 33 MPa 43 MPa

2.2 Coarse aggregates: Crushed stone aggregate (locally available) of maximum size 40mm, 20mm and 10mm were used in the various proportions throughout the experimental study and were tested as per Indian Standard Specifications IS: 383-1970. Table 2 shows the physical properties of coarse aggregates.

Table 2: Properties of Coarse Aggregates

Properties	Coarse Aggregates		
	10 mm	20 mm	40 mm
Colour	Grey	Grey	Grey
Shape	Angular	Angular	Angular
Specific Gravity	2.67	2.73	2.81
Water Absorption (%)	0.65	0.35	0.35
Bulk Density (kg/m^3)	1517	1556	1580

SELECTION OF MIX PROPORTION

Three trial mixes having cement to aggregate ratio 1:4, 1:6 and 1:8 were tested. These mixes having same proportion of 10mm, 20mm and 40mm maximum size aggregates. 1:8 mix gives compressive strength more than the minimum strength (3.5 MPa) required for the construction of pervious concrete pavements and high porosity as compare to

other two mixes (1:4 & 1:6) [12,15]. Therefore, 1:8 ratio mix can be used as pervious mix as it has low cement content.

PREPARATION OF TEST SPECIMENS

As discussed above, the mix proportion 1:8 was finally selected for determining the compressive strength, density, porosity and permeability of pervious concrete. The proportion of mix is 1 part of cement and 8 parts of aggregates with constant w/c ratio are given in Table 4. Six cubes of size 150mm x150mm x 150mm were casted. Three cubes from each mix were kept for determining the porosity, permeability, density of the mix and three cubes for compressive strength at age of 28 days of submerged water curing.

Table 4: Proportion of Aggregates with (1:8) mix

Mix Designation	Proportions of Coarse Aggregates of Size			W/C
	10 mm	20 mm	40 mm	
M_1	0	100	0	0.35
M_2	100	0	0	0.35
M_3	70	30	0	0.35
M_4	50	50	0	0.35
M_5	25	75	0	0.35
M_6	75	25	0	0.35
M_7	0	50	50	0.35
M_8	50	0	50	0.35
M_9	25	25	50	0.35
M_{10}	75	0	25	0.35
M_{11}	0	75	25	0.35
M_{12}	25	50	25	0.35
M_{13}	50	25	25	0.35
M_{14}	37.5	37.5	25	0.35
M_{15}	60	30	10	0.35

RESULTS AND DISCUSSIONS

Compressive Strength of Pervious Concrete

The compressive strength test for fifteen concrete mixes was conducted on Universal Testing Machine. The average value of results of three cubes represents the compressive strength of a mix at specified curing age of 28 days. Mix M_8 has highest and M_7 has the lowest compressive strength among all the mixes.[2]

Density of Concrete

Mix M_8 has the highest density value of 1967 Kg/m^3 and mix M_7 shows lowest density value of 1750 Kg/m^3 as shown in Table 5 [2]

Porosity of Concrete

Porosity test was conducted on self-made apparatus. The average of three samples was taken as the representative value of Porosity shown in Table 5.

The porosity of the cubes is then computed using

$$\text{Porosity, n} = \frac{\text{Volume of voids}}{\text{Total Volume}} = \frac{\text{Vv}}{\text{V}}$$

The porosity is mainly affected by the size of aggregate. In the present study, mix M_7 has maximum porosity of 30.2%.[2]

Permeability of Concrete

The permeability test was measured using the constant head method and permeability coefficient was calculated using formula:

$$k = \frac{QL}{AH}$$

Where, k – Coefficient of saturated permeability (m/hr)

Q – Volume of flow rate (m^3/s)

A – Cross-sectional area (m^2)

L – Specimen thickness in the direction of flow (m)

H – Head of water causing flow (m)

As the porosity is high, permeability of mix M_7 is highest i.e. 76.9m/hr and mix M_8 gave lowest value of permeability i.e. 21.7 m/hr due to its high density.[2]

Table 5: Mechanical Properties of Concrete Mixes at Age of 28 Days of Water Curing

Mix Designation	Compressive Strength (MPa)	Density (kg/m^3)	Porosity (%)	Permeability (M/Hr)
M_1	4.86	1794.7	27.6	50.9
M_2	5.85	1863.7	25.2	31.6
M_3	6.89	1925.0	24.3	28.4
M_4	5.48	1911.1	23.0	31.0
M_5	5.86	1878.5	23.8	35.7
M_6	5.58	1868.1	26.3	32.9
M_7	4.40	1751.1	30.2	76.9
M_8	7.29	1967.4	18.8	21.7
M_9	6.95	1955.6	23.0	28.5
M_{10}	6.06	1921.5	22.6	23.6
M_{11}	5.68	1851.9	27.0	44.0
M_{12}	5.97	1908.1	24.6	32.9
M_{13}	6.27	1914.0	20.3	27.8
M_{14}	6.11	1925.9	23.6	33.1
M_{15}	6.58	1914.1	22.4	22.6

Relation between Different Properties of Pervious Concrete

Porosity and Compressive Strength

Figure 1 shows the variation of compressive strength and porosity for all the concrete mixes. The mean curve drawn through the data has the equation

$$\sigma_c = -0.218n + 11.27 \quad \text{(i)}$$

Here ‘σ_c’ is the compressive strength of concrete in MPa and ‘n’ is the porosity of concrete in percentage. The coefficient of determination (r^2) for the relationship is 0.665.

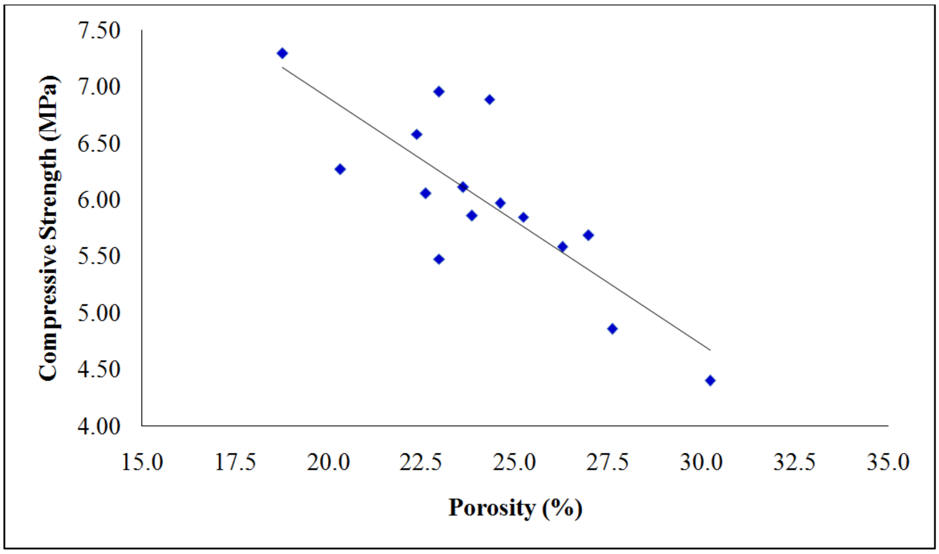

Figure 1: Relationship between Compressive Strength and Porosity

Density and Compressive Strength

Figure 2 shows the variation of compressive strength and density for all the concrete mixes. The mean curve drawn through the data has the equation

$$\sigma_c = -0.012\gamma - 16.84 \qquad \text{(ii)}$$

Here 'γ' is the density of concrete in kg/m^3. The coefficient of determination (r^2) for the relationship is 0.829.

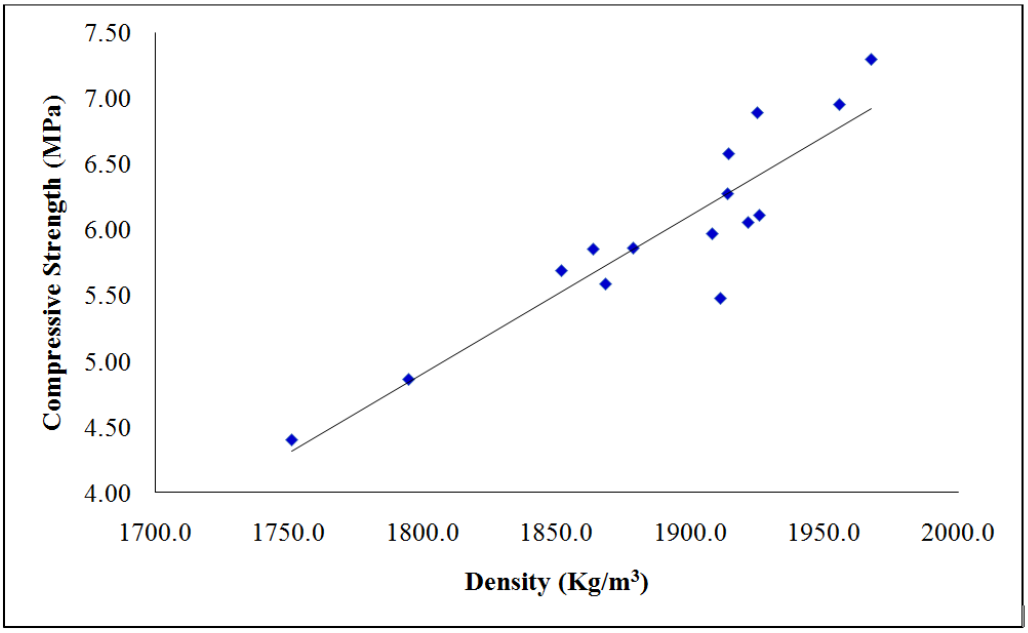

Figure 2: Relationship between Compressive Strength and Density

Density and Porosity

Figure 3 shows the variation of density and porosity for all the concrete mixes. The mean curve drawn through the data has the equation

$$\gamma = -17.93n + 2323 \quad \text{(iii)}$$

The coefficient of determination (r^2) for the relationship is 0.787.

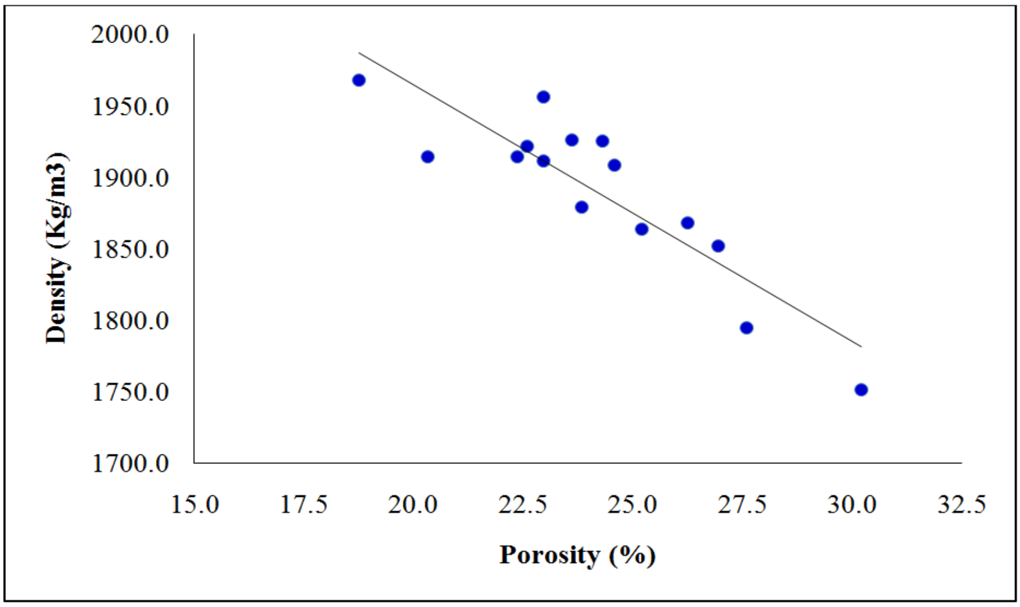

Figure 3: Relationship between Density and Porosity

Porosity and Permeability

Figure 4 shows the variation of permeability and porosity for all the concrete mixes. The mean curve drawn through the data has the equation

$$k = 2.8005e^{0.109n} \quad \text{(iv)}$$

Here 'k' is the permeability of concrete in m/hr. The coefficient of determination (r^2) for the relationship is 0.792.

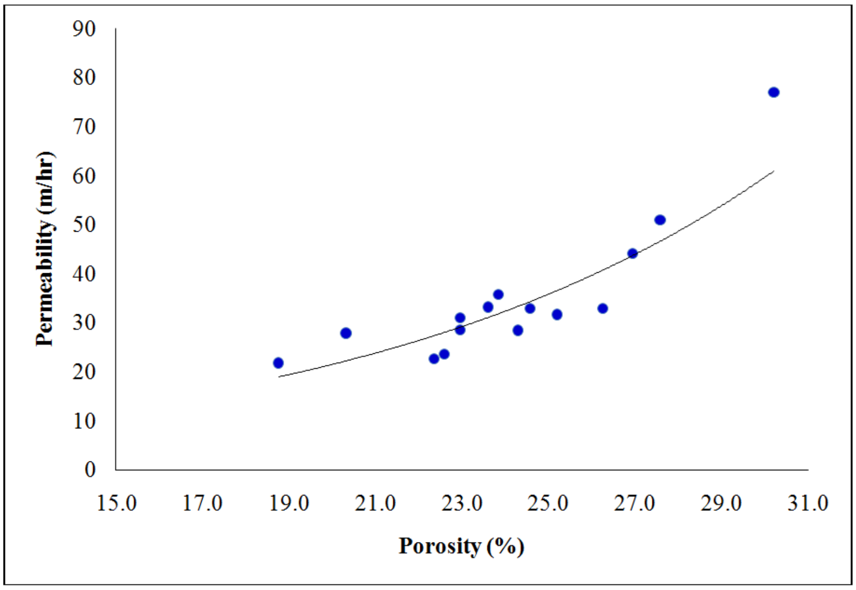

Figure 4: Relationship between Porosity and Permeability

Density and Void Ratio

Figure 5 shows the variation of density and void ratio for all the concrete mixes. The mean curve drawn through the data has the equation

$$\gamma = -1033.4e + 2221.2 \quad \text{(v)}$$

Here 'e' is the void ratio of concrete. The coefficient of determination (r^2) for the relationship is 0.811.

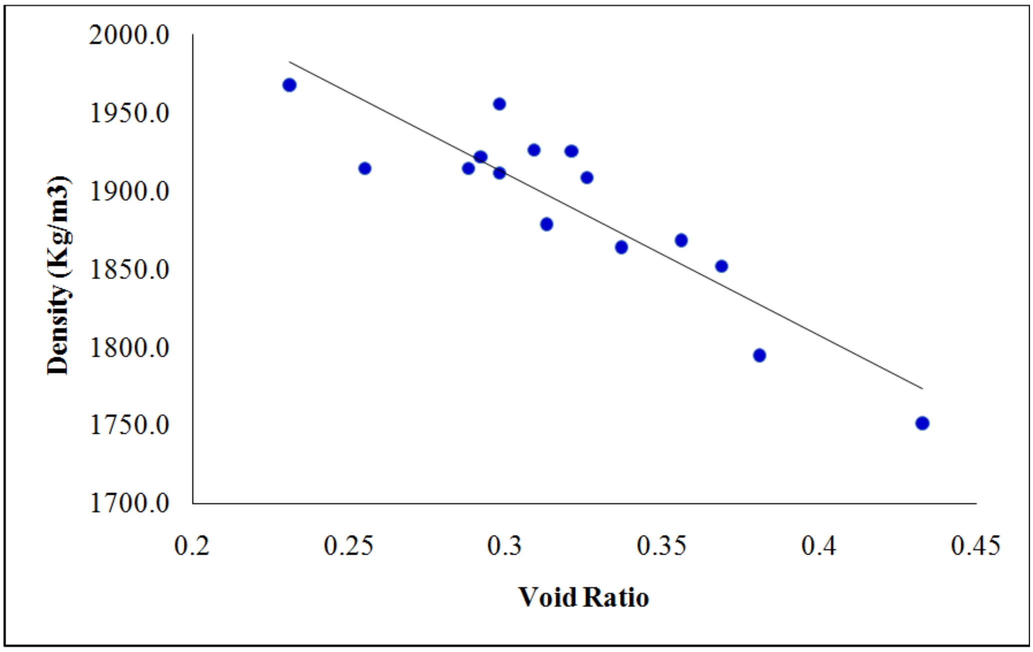

Figure 5: Relationship between Density and Void Ratio

Compressive strength and Permeability

Figure 6 shows the variation of compressive strength and permeability for all the concrete mixes. The mean curve drawn through the data has the equation

$$\sigma_c = 7.8971e^{-0.008k} \quad \text{(vi)}$$

The coefficient of determination (r^2) for the relationship is 0.742.

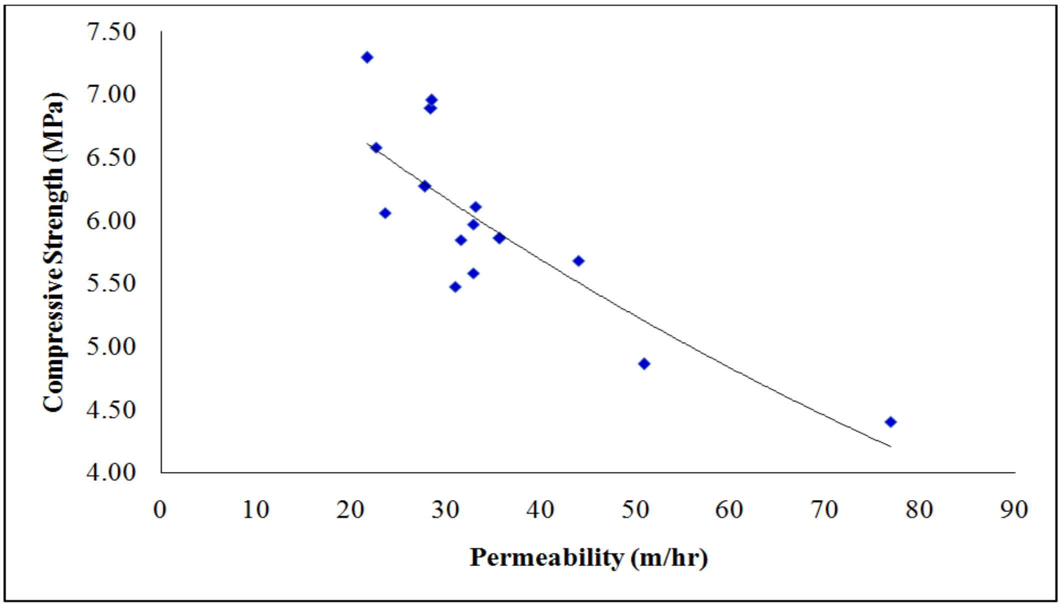

Figure 6: Relationship between Compressive Strength and Permeability

Development of Prediction Equation for Compressive Strength, Permeability and Density

As discussed in previous section, it is seen that the compressive strength, permeability and density depends upon the proportions of the aggregates used. Also the compressive strength, permeability and density depend upon the w/c ratio and the quantity of cement used in the mix. So an attempt is made to relate the compressive strength, permeability and density with all the parameters. Regression analysis is performed by using curve expert software to generate the best fit equation for compressive strength, permeability and density.

The compressive strength of concrete is given as

$$\sigma_c = 10.58 - 0.444x_1 - 0.62x_2 - 0.47x_3 - 1.59x_4 \quad \text{(vii)}$$

where x_1 = weight of 10mm size aggregates/weight of cement, x_2 = weight of 20mm size aggregates/weight of cement, x_3 = weight of 40mm size aggregates/weight of cement and x_4 = w/c. For the equation (vii), the coefficient of determination (r^2) is 0.45 and the correlation coefficient (r) is 0.67.

The permeability of concrete is given as

$$k = -2.693 + 2.543x_1 + 6.451x_2 + 6.767x_3 - 0.943x_4 \quad \text{(viii)}$$

For the equation (viii), the coefficient of determination (r^2) is 0.49 and the correlation coefficient (r) is 0.70.

The density of concrete is given as

$$\gamma = 1931.91 - 28.98x_1 - 43.05x_2 + 34.46x_3 + 676.17x_4 \quad \text{(ix)}$$

For the equation (ix), the coefficient of determination (r^2) is 0.40 and the correlation coefficient (r) is 0.63.

Verification of the Developed Relationship

The developed relationship for determining the compressive strength, permeability and density are used to estimate these parameters for all the 15 mixes.

- **Checking of Equation for Predicting Compressive Strength of Concrete**

Equation (vii) is used to find the compressive strength of the concrete mixes and the trial mixes M_{T1}, M_{T2} and M_{T3}. Table 6 shows the estimated compressive strength using equation (vii). The measured values of compressive strength are also shown in this table. Figure 7 shows the variation of estimated compressive strength and measured compressive strength for different mixes. ±15% error line is also drawn in the Figure4.22. It is observed that 83.4% of values fall in the ±15% range.

Table 6: Estimated and Measured Compressive Strength for all Mixes

Mixes	Estimated Compressive Strength (MPa)	Measured Compressive Strength (MPa)
M_1	5.06	4.86
M_2	6.47	5.85
M_3	6.04	6.89
M_4	5.76	5.48
M_5	5.41	5.86
M_6	6.11	5.58
M_7	5.66	4.40
M_8	6.36	7.29
M_9	6.01	6.95
M_{10}	6.41	6.06
M_{11}	5.36	5.68
M_{12}	4.82	5.97
M_{13}	6.06	6.27
M_{14}	5.89	6.11
M_{15}	6.02	6.58
M_{T1}	8.02	8.01
M_{T2}	7.02	5.60
M_{T3}	6.02	5.47

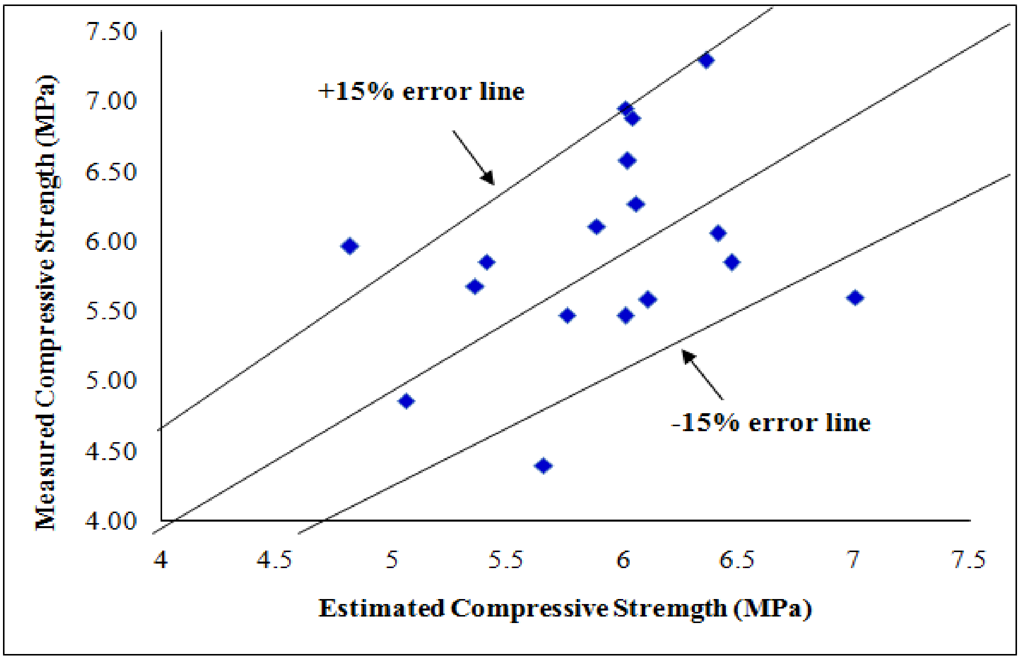

Figure 7: Estimated Versus Measured Compressive Strength

- **Checking of Equation for Predicting Permeability of Concrete**

Equation (viii) is used to find the permeability of the concrete mixes. Table 7 shows the estimated permeability using equation (viii). The measured values of permeability are also shown in this table. Figure 8 shows the variation of estimated permeability and measured permeability for different mixes. ±15% error line is also drawn in the Figure 8. It is observed that 53.3% of values fall in the ±20% range.

Table 7: Estimated and Measured Coefficient of Permeability for All Mixes

Mixes	Estimated Coefficient of Permeability (m/hr)	Measured Coefficient of Permeability (m/hr)
M_1	48.6	50.9
M_2	17.3	31.6
M_3	26.7	28.4
M_4	33.0	31.0
M_5	40.8	35.7
M_6	25.1	32.9
M_7	49.8	76.9
M_8	34.2	21.7
M_9	42.0	28.5
M_{10}	25.8	23.6
M_{11}	49.2	44.0
M_{12}	46.5	32.9
M_{13}	33.6	27.8
M_{14}	37.5	33.1
M_{15}	30.1	22.6

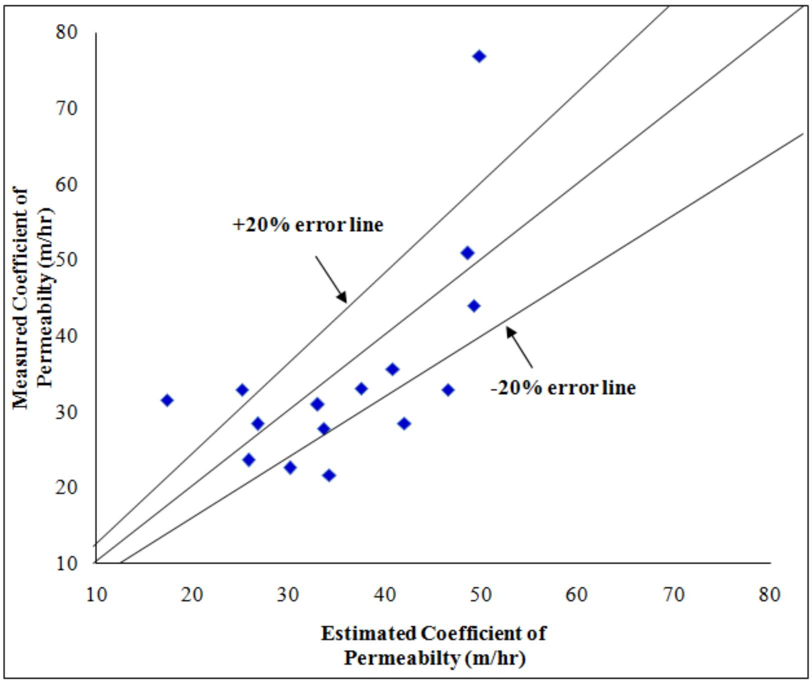

Figure 8: Estimated Versus Measured Coefficient of Permeabiity

c) Checking of equation for predicting density of concrete

Equation (ix) is used to find the permeability of the concrete mixes. Table 8 shows the estimated density using equation (ix). The measured values of density are also shown in this table. Figure 10 shows the variation of estimated

density and measured density for different mixes. ±5% error line is also drawn in the Figure 9. It is observed that 86.7% of values fall in the ±5% range

Table 8: Estimated and Measured Density for all Mixes

Mixes	Estimated Density (kg/m^3)	Measured Density (kg/m^3)
M_1	1824.2	1794.7
M_2	1936.7	1863.7
M_3	1903.0	1925.0
M_4	1880.5	1911.1
M_5	1852.3	1878.5
M_6	1908.6	1868.1
M_7	1858.5	1751.1
M_8	1914.8	1967.4
M_9	1886.7	1955.6
M_{10}	1925.8	1921.5
M_{11}	1841.4	1851.9
M_{12}	1811.5	1908.1
M_{13}	1897.6	1914.0
M_{14}	1883.6	1925.9
M_{15}	1898.6	1914.1

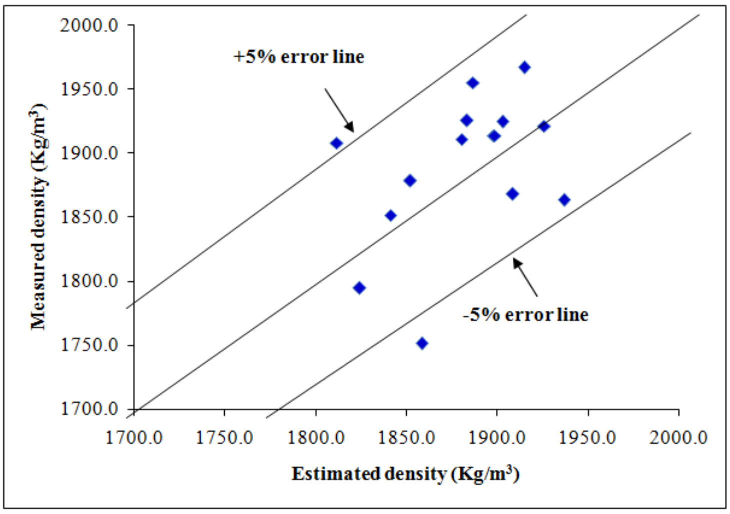

Figure 9: Estimated Versus Measured Density

CONCLUSIONS

Graphical analysis on laboratory research was carried out to drive prediction equations of pervious concrete. Present study was carried out to determine the compressive strength, porosity and permeability of pervious concrete having different proportion of aggregates. From the experimental results the following conclusion can be drawn:

- The curve drawn between the different parameters gives the equation with high value of coefficient of determination (r^2) ranging from 0.665 to 0.829.
- Variation between different properties of all mixes shows similar pattern as expected.
- Prediction Equations derived for compressive strength, permeability & density has low value of coefficient of determination (r^2), which means these equation depends on more variables which are not considers.

- Mix M_5 or M_{14} has come out to the best mix with high permeability and adequate strength. Therefore, it can be applied to both walkways and footpaths.

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